Title

Porous stones increase the noise shielding of a gabion

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Abstract

Gabions - metal-wired cages filled up with stones - are increasingly becoming popular as decorative elements and land property boundaries. It has been shown before that such structures can be used as road traffic noise barriers as well. However, the types of stones used in gabions have not been experimentally studied so far. Exploratory measurements at full scale in a semi-anechoic room were performed to study the effect of both porous and rigid stones on their noise reducing potential. At the 1/3 octave bands below 1 kHz, low-height gabions (with depths of 20 cm and 30 cm) hardly provide any sound pressure level reduction. At higher sound frequencies, in contrast, the shielding rapidly increases. Porous lava stones were found to significantly increase the shielding compared to rigid stones. Reflections on such non-deep low-height barriers towards the source side were found to be of minor importance when considering a standardized A-weighted road traffic noise spectrum.

[**keywords** : noise barriers; gabions; diffraction; transmission; natural solutions]

1.Introduction

Gabions are cages or boxes made of steel wire, filled with stones. Although such structures were traditionally used as foundations or to prevent erosion (e.g. river bank protection), they are becoming popular as a decorative element in gardens or to define land property boundaries. Advantages are their natural look and lack of maintenance. They are often used to replace vegetative hedges.

There has been some interest in the sound reducing potential of gabions. Koussa et al. [1] reported full scale in-situ measurements of the reflection index and transmission loss of a 3-m high and 1.1-m wide gabion made of crushed rigid stones. The single number ratings of the reflection and insulation indices were measured to be near 5 dB and 20 dB, respectively. Scale model studies [1] and numerical work [1] considering 1-m wide and 1-m high gabions showed that near 8 dBA road traffic noise insertion loss can be obtained at ear height, at 5 m distance from the gabion. Optimization by making the gabion a layered structure of stones with different sizes was numerically explored and seems possible [1]. Vegetative hedges, in contrast, were measured to only provide minor sound pressure level reduction [2], although the noise perception improvement is potentially strong [3].

A low-height barrier, in general, can be quite efficient for a low-height sound source if the source appears at close distance from the barrier. Such conditions can be met in case of rail or road traffic. These low barriers, even when they can be overlooked (e.g. lower than 1 m high), were shown to be efficient to shield specific zones, also in an urban context [4][5][6][7][8][9][10].

So it can be concluded that low-height gabions can be effective in reducing noise. However, the type of stones used to fill the cage did not receive a lot of attention so far. Initial numerical simulations showed that the noise shielding of a gabion could be theoretically enhanced by using porous stones instead of rigid ones [11]. Since gabions can be categorized as “leaky” barriers, additional absorption during transmission could lead to better acoustic insulation. At the same time, the interaction with absorbing material during diffraction over a barrier could make such paths less intense as well [12][13]. Thirdly, absorption at the vertical barrier face at the source side could lead to a smaller amount of reflected sound energy.

In this work, exploratory full scale measurements were performed under well controlled conditions, comparing low-height gabions containing either porous or rigid stones. In contrast to the aforementioned 1-m wide gabions discussed in Ref. [1], the measurements in this study were restricted to barrier depths of maximum 30 cm. This is more related to the practical use of gabions positioned at plot borders near dwellings.

2.Material and methods

2.1.Diffraction experiment in semi-anechoic chamber

The measurements were performed at full-scale in the semi-anechoic chamber at Ghent University with dimensions 5 m by 8 m. The cut-off frequency (99% absorption) of the 1.2-m long melamine pyramids is 63 Hz. The measured A-weighted background noise levels are below the noise floor of a type-1 measurement chain using a ½” microphone capsule (< 15 dBA). Given the large weight of a filled gabion, these measurements cannot be performed in a full anechoic chamber. However, the fully rigid floor will give rise to pronounced interferences that will shift between the reference situation (i.e. unscreened ground) and the sound propagation case in presence of the gabion. Although this will make spectral insertion losses somewhat less clear, it is nevertheless more closely related to practice.

2.2.Gabion barriers

Three different gabion setups were tested, namely a 20-cm thick gabion filled with rigid stones (see Fig. 1, stone size distribution between 4 cm and 6 cm), a 20-cm thick gabion with porous lava stones (see Fig. 2, stone size distribution between 4 cm and 8 cm), and a 30-cm thick gabion with the same lava stones. To prevent excessive bending of the 2-m high metal structure (that could obviously not be screwed in the floor) and for safety reasons, the filling height has been limited to 1.6 m. In case of the 30-cm thick gabion setup, the height was limited to 1.4 m. The combined effect of the cage (consisting of 3-4 mm metal wires, forming a lattice of square openings of 5 cm by 5 cm), the metal U-profile at the bottom (with a height of 10 cm) and the supporting poles have been measured as well without stones (see Figure 3).

Figure 1. Photograph of the rigid stones filling up the metal cage.

Figure 2. Photograph of the porous lava stones.

Fig. 3. Photograph of the empty gabion positioned in the semi-anechoic room.

2.3.Measurement equipment and signal processing

Four type-1 half-inch MK250 (Microtech Gefell) microphone capsules were used (with a fully flat response in the frequency range considered, see further), connected to SV12L (Svantek) preamplifiers. For the data acquisition, a National Instruments PXIe-1082 chassis with three NI-4498 data acquisition cards were used, steered by a Labview application to perform the processing to sound pressure levels. After each microphone manipulation (e.g. moving and reconnecting), the calibration was repeated with a SVAN30A (Svantek) type-1 pistonphone, producing a pure tone of 1 kHz at 94 dB. Throughout the full experiment the needed adjustments were 0.2 dB (root-mean-square value, considering all microphones channels).

The frequencies of interest were the 1/3 octave bands from 100 Hz to 8 kHz. Linear and logarithmic sweeps of 60 s covering this frequency range were emitted. These sound signals were sent by Labview to an external sound card type ESI U24XL (24 bits) and forwarded to a power amplifier A-607R (Pioneer) on “direct” mode, driving an OmniSource loudspeaker type 4295 (Bruel & Kjear). This loudspeaker directs sound through a conical coupler connected to a circular orifice, approaching a point source, yet with sufficient sound power.

Each sample was repeated 3 times and the one-minute equivalent sound pressure levels were linearly averaged afterwards. The variation on these repeatedly measured levels were very minor (much lower than 0.1 dB), pointing at highly consistent measurements as can be expected when experimenting in an anechoic room.

Insertion losses were calculated by subtracting the sound pressure levels in case of unscreened ground with the ones when the gabion was present. In a next step, the spectral insertion losses were summarized to total A-weighted white and pink noise insertion loss. In addition, the insertion losses were calculated using the (A-weighted) road traffic noise spectrum weighting according to EN 1793-3 [15]. Deviations from a flat spectral amplitude response by the loudspeaker were corrected for based on the product description by the vendor. Below 1 kHz, the sound source was measured (by the vendor) to be truly omnidirectional. At higher sound frequencies, the sound source becomes somewhat more directive and reported deviations (by the vendor, following ISO 3382) were at maximum 5 dB at 8 kHz. The loudspeaker exit was directed towards the gabion, and this orientation was maintained throughout the whole experiment. Therefore, the high frequency non-directionality is expected to have a minor influence only on the measured insertion losses.

2.4.Microphone and source positioning

Two microphone setups were considered. In a first one (see Fig. 4 (a) and (b)) the source was placed at close distance from the gabion (at 1 m), at half the screen height (0.8 m). Two microphones (MP1 and MP2) were placed directly behind the barrier in order to minimize diffraction around the vertical edges of the barrier. These microphone positions are expected to be mainly governed by sound transmission through the barrier. The symmetrical positioning relative to the source and the vertical barrier edges allows checking the uniformity of the acoustic response at close distance. These microphone placements are partly inspired by existing in-situ methodologies (see e.g. Ref. [14]), although fully separating transmission from the diffraction paths was not the main aim in these exploratory measurements. A third microphone (MP3) is placed at maximum distance relative to the barrier. In addition, another microphone (MP4) was placed at the source side to estimate the importance of reflections on the barrier.

The second microphone setup (see Fig. 4, (c) and (d)) allows measuring the performance in a more representative road traffic noise situation. The source was placed as far as possible from the barrier, at a lower height (0.35 m). This configuration will give rise to a larger contribution of diffracted sound paths, both along the horizontal and vertical edges of the gabion. If such barriers are to be considered as a personal noise reducing device on one’s own property, such a limited length will be part of practice.

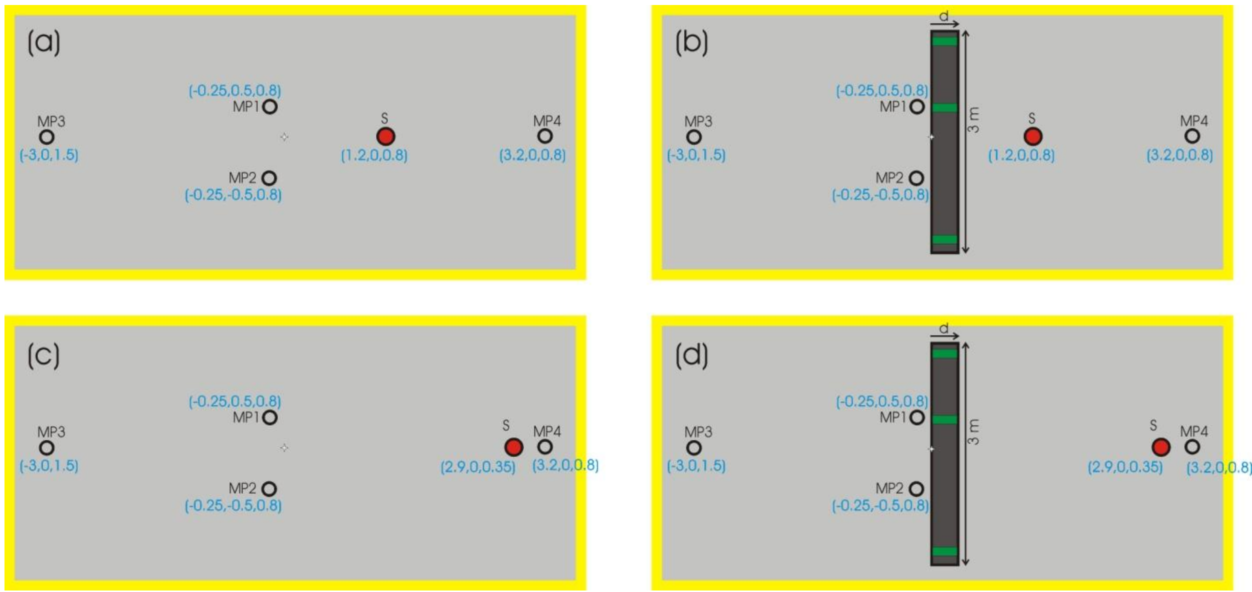

Figure 4. Gabion, source (S) and microphones positioning (MP) in the semi-anechoic room at Ghent University. In (a) and (b), there is a close source positioning, in (c) and (d) the source is placed further away from the wall. (a) and (c) serve as reference measurements (unscreened ground) for gabion setups (b) and (d), respectively. The exact locations of the microphones are indicated by their (x,y,z) coordinates, with z the microphone membrane height. Gabion depths d are either 20 cm or 30 cm.

3.Results and discussion

3.1. Positioning errors

When changes were made to the barrier setup, the microphones were evacuated from the anechoic room in order not to damage the measurement equipment. In a next step, the microphones were manually repositioned at their original location as accurate as possible, but this inevitably lead to positioning errors.

Such errors have been quantified in case of unscreened rigid ground i.e. the reference case (a) (see Fig. 4) in this study. Under these conditions, interferences between the direct and ground-reflected sound path are expected to be most pronounced. The sound pressure level measurements in this case are thus most sensitive to positioning errors. The difference in sound pressure level is measured as a result of placing the microphones two times (by the same operator), for each of the 4 microphones. In a next step, the standard deviations on these sound pressure levels have been calculated and are presented in Figure 5. There is a general trend towards an increased standard deviation with increasing frequency since the error is expected to be proportional to the ratio between the positioning error and the wavelength. However, on top of that, some peaky behavior is observed due to shifting specific interferences.

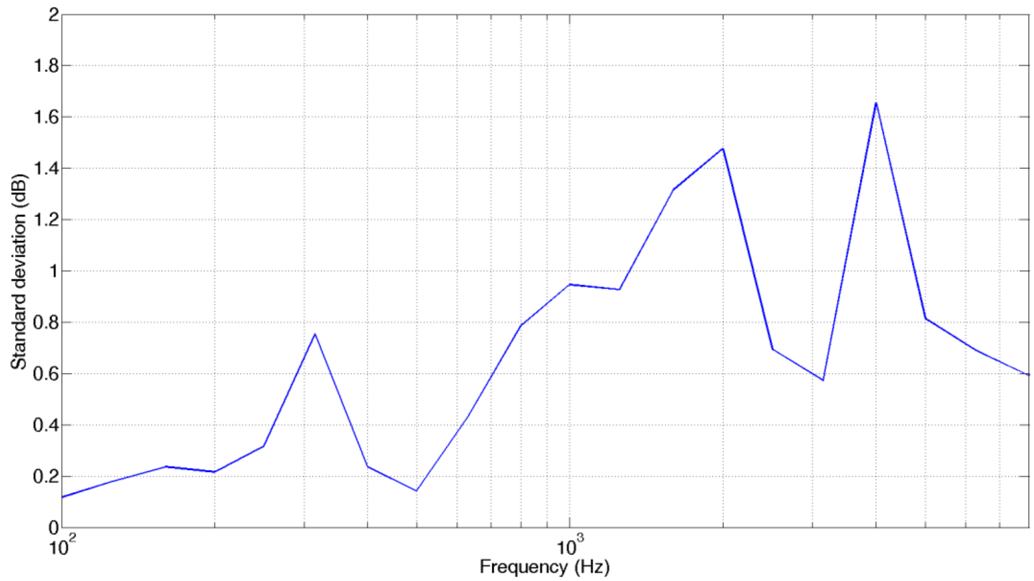

Fig. 5. Variation in sound pressure level due to manual microphone positioning in case of an unscreened rigid floor [see Fig. 4, setup (a)].

3.2. Spectral insertion losses

The spectral insertion losses for the different types of barriers, for both the close and far source positioning, are depicted in Figs. 6 and 7. At low frequencies, the gabions provide less than 5 dB noise reduction at MP1, MP2 and MP3. Starting from about 1 kHz, the shielding strongly increases and might reach 25 dB in the frequency range considered. The receivers in the deep shadow zone (i.e. MP1 and MP2), although positioned symmetrically relative to the source and barrier, show rather different insertion loss spectra. The non-uniform filling of the cages with stones, the non-symmetric positioning of the poles, but also microphone positioning errors, are responsible for this.

The empty container has a non-negligible effect on the insertion loss (see Fig. 6). Especially the poles and the U-profile will partly shield and scatter sound. Scattered sound waves might interfere with other sound paths, leading to specific interference patterns depending on source and receiver positioning. In the low frequency range, a similar spectral pattern is observed at MP1 and MP2. At higher sound frequencies, somewhat larger shielding is observed at MP1 relative to MP2, most likely due to its closer positioning relative to one of the poles. Above 1 kHz, the shielding mainly comes from the presence of the stones.

The lava stones enhance the shielding relative to the rigid stones. This effect is most pronounced in the higher frequency range. Increasing gabion thickness (in case of the porous stones) leads to higher sound shielding, however, this does not hold for all 1/3 octave bands considered. Note, however, that the 30-cm thick barrier has a somewhat lower pile-up height. This larger thickness seems more important for the shielding than the small difference in filling height. The difference between MP1 and MP2 is further enhanced when looking at the gain one might get from increasing gabion thickness.

The stones are mainly responsible for reflections coming from the gabion. In case of the empty cage and poles, the insertion losses stay very close to zero (see Fig. 6, MP4). The different gabions considered do not influence reflections significantly for the close source positioning (see Fig. 6). All together, reflections lead to slightly negative insertion losses, increasing the sound pressure levels somewhat at the receiver MP4 positioned at the source side. Exceptions are found at some frequency bands where interferences shift. This occurs at low frequencies for the close spacing of the source, and at higher frequencies for the far spacing of the source. In the latter, this is probably due to a higher sensitivity to microphone positioning. Conclusions regarding which type of gabion leads to more reflected sound energy cannot be made based on current measurement methodology.

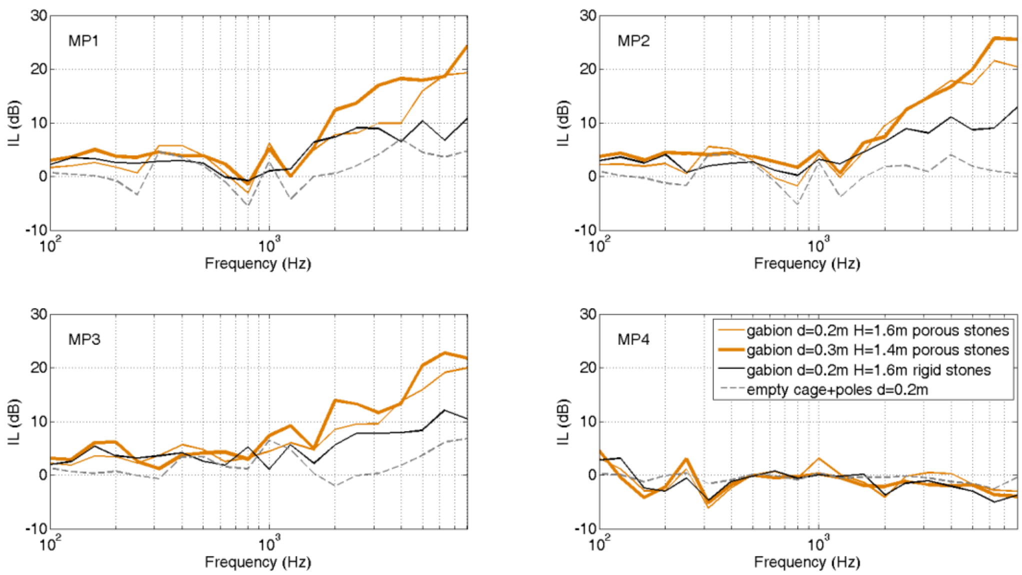

Figure 6. Measured spectral insertion losses at the different microphone positions considered. Microphone and source positioning according to setups (a) and (b) as shown in Fig. 4.

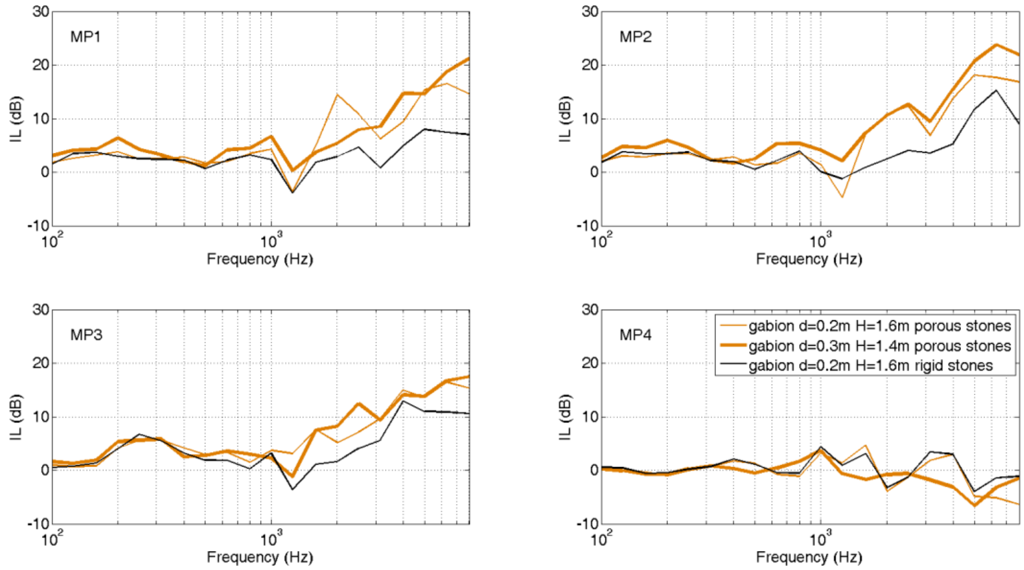

Figure 7. Measured spectral insertion losses at the different microphone positions considered. Microphone and source positioning according to setups (c) and (d) as shown in Fig. 4.

3.3. Overall insertion losses

Table 1 and 2 present overall insertion losses, for white noise, pink noise and a standardized road traffic spectrum [15] (all A-weighted). The white noise insertion loss puts a larger emphasize on high sound frequencies than pink noise, which on its turn is more dominated by higher frequencies than the traffic noise spectrum. Consequently, white noise insertion losses are higher than pink noise and traffic noise insertion losses given that the gabions act more or less as a low-pass filter.

The maximum measured white noise insertion loss is 10.9 dBA for the 30-cm thick gabion filled with porous stones for the close source spacing at MP3. For the traffic noise insertion loss, this value reaches 5.9 dBA. A comparison with the measurements of the empty container learns that the stones alone are responsible for 8.0 dBA and 3.4 dBA insertion loss at MP3, for white noise and road traffic noise, respectively. The peak in spectral insertion loss centered around 1 kHz (see Fig. 6) and the peaked behavior of the road traffic spectrum in this same frequency range make that the empty container takes a significant part of the overall insertion loss of the complete gabion (container and stones) at MP3.

In case of the far source setup, which is closest to a practical road traffic noise case, road traffic noise insertion losses are more modest and might reach 3.7 dBA at MP3 in case of the 30-cm thick gabion filled with lava stones. A 20-cm thick gabion with lava stones hardly reduces this overall insertion loss relative to the thicker barrier, and was measured to be 3.6 dBA. Porous stones are –relatively spoken- a significant improvement relative to rigid stones with a bonus of 1.7 dBA for a 20-cm thick gabion. Negative effects resulting from reflections were not measured for road traffic noise in this far source setup.

Table 1. Measured insertion losses for total A-weighted white noise, A-weighted pink noise and a standardized (A-weighted) traffic noise spectrum following EN 1793 [15]. Microphone and source setups (a)-(b) (see Fig. 4, close source).

	white noise (dBA)	pink noise (dBA)	traffic noise (dBA)
gabion (d=0.2 m, lava stones, H=1.6 m)			
MP1	7.6	4.7	3.0
MP2	7.8	4.4	2.6
MP3	8.8	6.0	4.5
MP4	-0.7	-0.3	-0.1
gabion (d=0.3 m, lava stones, H=1.4 m)			
MP1	8.8	5.4	3.5
MP2	8.8	5.6	3.8
MP3	10.9	7.6	5.9
MP4	-1.5	-0.9	-0.6
gabion (d=0.2 m, rigid stones, H=1.6 m)			
MP1	5.9	3.8	2.2
MP2	6.7	4.6	3.1
MP3	6.9	4.8	3.7
MP4	-1.7	-0.7	-0.3
only cage+poles			
MP1	1.9	0.5	-0.4
MP2	0.8	0.2	-0.2
MP3	2.9	2.5	2.5
MP4	-0.7	-0.5	-0.3

Table 2. Measured insertion losses for total A-weighted white noise, A-weighted pink noise and a standardized (A-weighted) traffic noise spectrum following EN 1793 [15]. Microphone and source setups (c)-(d) (see Fig. 4, far source).

	white noise (dBA)	pink noise (dBA)	traffic noise (dBA)
gabion (d=0.2 m, lava stones, H=1.6 m)			
MP1	8.7	5.4	3.2
MP2	9.3	5.5	3.1
MP3	8.0	5.6	3.6
MP4	-0.9	0.2	0.6
gabion (d=0.3 m, lava stones, H=1.4 m)			
MP1	8.0	5.3	3.7
MP2	11.2	7.2	4.7
MP3	9.1	6.0	3.7
MP4	-1.5	-0.5	0.1
gabion (d=0.2 m, rigid stones, H=1.6 m)			
MP1	4.1	2.8	2.0
MP2	4.9	3.0	2.1
MP3	4.3	2.7	1.9
MP4	0.4	0.7	0.8

4.Conclusions

Full-scale exploratory measurements under well-controlled conditions in a semi-anechoic room were performed to investigate the influence of two types of stones used to fill low-height gabions of limited depth. It was found that porous lava stones significantly increase the shielding relative to rigid stones.

At 1/3 octave bands below 1 kHz, the lava stones hardly provide any sound pressure level reduction with respect to rigid stones. At higher sound frequencies, in contrast, the additional shielding provided by the porous stones rapidly increases. However, road traffic noise shielding by such non-deep gabion barriers is expected to be rather low in realistic applications, and much deeper barriers are needed to achieve significant insertion losses. Reflections on such barriers towards the source side are of minor importance.

Acknowledgements

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